Acoustical Studies Of Sediment Dynamics In The Surf Zone: Sandyduck'97

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LONG-TERM GOALS

The central goal of this project is a deeper understanding of the dynamic adjustment of mobile sandy sediments to fluid forcing in and near the surf zone at small (1cm to 10m) and intermediate (10m to 100m) horizontal scales. The effort is motivated by the dual need to develop more realistic models of fluid-sediment interactions in the nearshore zone, and for suitable in situ measurement techniques to make the observations necessary to adequately test the models.

OBJECTIVES

The primary objectives of this project are: (1) to study the role of bedforms of different characteristic spatial pattern and scale in the local sediment flux and momentum balances, and (2) to investigate bedform genesis, growth, migration, and decay in relation to the fluid forcing conditions and predicted sediment transport rates. Of particular interest are the relationships between sediment fluxes, bedform properties, and asymmetries in the fluid motions. A key initial objective was to obtain a comprehensive set of measurements of bed adjustment through time, as a function of cross-shore position, and over a period of several months. This data set was obtained in SANDYDUCK, and is providing a basis for determining cross-shore differences in response synoptically, and for differences in the response trajectories through time and between forcing events, over a suitably wide range of conditions.

APPROACH

The approach for the SANDYDUCK '97 experiment involved an array of state-of-the-art underwater acoustic sensors for high-resolution measurements of seabed topography, and fluid velocity and sediment concentration profiles through the wave-current boundary layer. The array comprised 5 instrumented frames deployed along a cross-shore line and along an alongshore line with 50-100 spacing between adjacent frames. Rotary fan and pencil-beam imaging sonars were mounted on each frame. Coherent Doppler Profiler (CDP) systems, augmented by Sontek ADV-O point velocimeters, were mounted on two of the frames. Ancillary sensors on each frame included pressure and temperature sensors, and electromagnetic flowmeters, and 2-axis tilt sensors.

The coherent Doppler system (Zedel and Hay, 1999) was developed collaboratively with Dr. Len Zedel (Memorial University), with funds from ONR. The rotary sonar system operates in master/slave mode, with custom electronics developed at Dalhousie prior to SANDYDUCK, in order that data from a number (up to 8) different heads may be acquired simultaneously. The data acquisition and control system is PC- and PC-104-based, with multiple surface and underwater data acquisition and control nodes operating time-synchronously in a multi-tasking UNIX-like environment on a combination ethernet/ ARCnet network. Technical support for the system is provided by Wes Paul (electronics and acoustics technologist) and Dr. Robert Craig (data acquisition and control software). The em flowmeters and pressure/temperature measurements in SANDYDUCK were made by colleague Dr. Tony Bowen (Dalhousie University), as part of a separately-funded collaborative research project. David Hazen (electronics engineer) and Walter Judge (electronics technologist) provided additional technical support.

The data volume collected with these systems can be large, and the processing requirements significant. A reasonably powerful acoustic data processing capability has developed incrementally over the last 2-3 year. The system currently comprises 6 Unix workstations and about 200 Gbytes of disk space. Research Assistant Todd Mudge is responsible for the operation of the system, in addition to assisting with the data analysis.

Postdoctoral fellow Dr. Qingping Zou is participating in the analysis of the CDP data, and carrying out theoretical analyses of the hydrodynamics. Dr. Diane Foster (Ohio State University) is collaborating with us on bottom boundary layer dynamics. Doctoral student Carolyn Smyth is playing a leading role is the analysis of the CDP data. Doctoral student Phil MacAulay is using acoustic images of the space-time structure of suspension for his thesis. Dr. J. C. Doering and his students are working with the ADV data. Other collaborations include Dr. Rebecca Beavers (University of North Carolina) and Dr. Peter Howd (University of South Florida), on sediment fabric, and Dr. Tom Lippmann (Ohio State University) on processes related to wave breaking.

WORK COMPLETED

During SANDYDUCK approximately 250 GBytes of high-quality acoustic data were acquired continuously over a 77-day period from late August to early November.

Two problems were encountered with the SANDYDUCK data. One was the orientation of the pencil-beam images relative to gravity due to intermittent discrepancies in the measured direction of the sonar head. The other was a discrepancy in the velocities measured by the CDP and other results. These problems have both now been resolved, and we are producing final data products.

RESULTS

A focus of the past year has been the genesis and migration of different ripple types. One of the goals of this work is to attempt to better establish the relationship between sediment transport models and the moments of the velocity field (as in energetics-based models), or to better constrain the value of the exponent in the power-law relationship between transport and stress (Hay and Bowen 1999) in the case of stress-based models. As part of this work, we are implementing several different analysis methodologies suitable for the range of bedform types observed during SANDYDUCK. One such approach, developed for lunate megaripples and other individually-distinct features in the fanbeam imagery, uses edge detection analysis to reduce the Mbyte-sized 2-d image to a single vector representing the positions of the edge. Edges of the same feature from successive images allow the size and position of the image to be followed through time. An example of this approach is shown in Figure

1, in which both the extracted edge and a polynomial fit to the edge are plotted at 1/2-h intervals for an onshore-migrating lunate megaripple. As well as the migration, the extracted edges clearly show the growth of this feature. Note also that the polynomial provides quite a reasonable fit to the edge data.

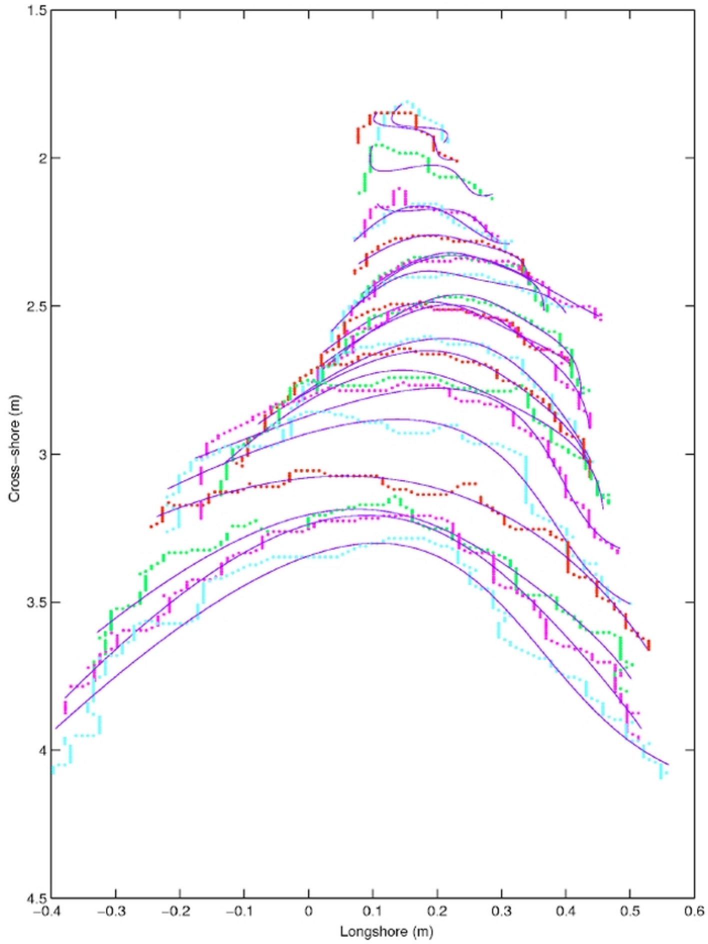

Figure 1: Time sequence of the extracted edges of a shoreward-migrating lunate megaripple, and the polynomial fits (in blue) from half-hour separated acoustic fanbeam images during SANDYDUCK.

The edge detection method, as we have implemented it at least, is not as suitable as other techniques for ripple fields with a higher degree of spatial periodicity than lunate megaripples. For such fields we have been separating the spatial frequency spectrum into different frequency bands, and performing a time-space correlation analysis within each band to extract migration velocities. Figure 2 shows the migration rates obtained with this method in the 0.5-3 cpm band, plotted against wave orbital velocity skewness, for the entire SANDYDUCK experiment at three of our instrument frames. While there is certainly a lot of scatter, there is a clear tendency for onshore migration to increase with positive skewness.

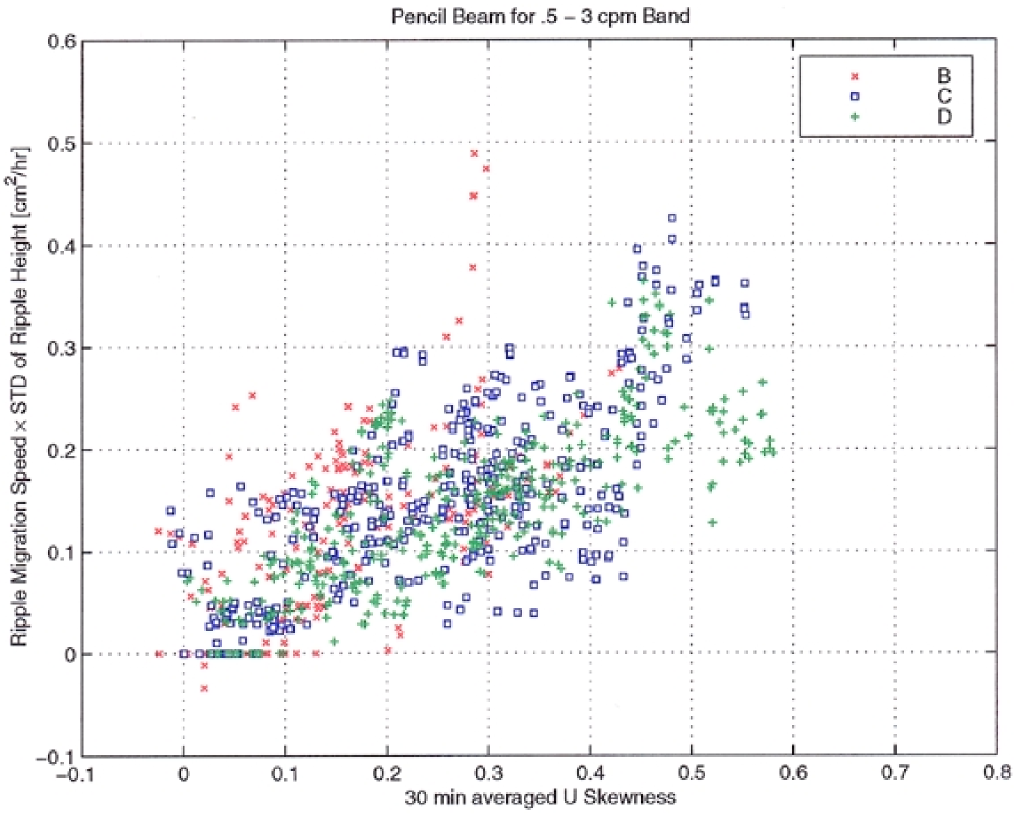

Figure 2: Scatter-plot of cross-shore bedform migration velocities (multiplied by rms ripple height) versus incident wave band skewness during SANDYDUCK. The different symbols represent different frames.

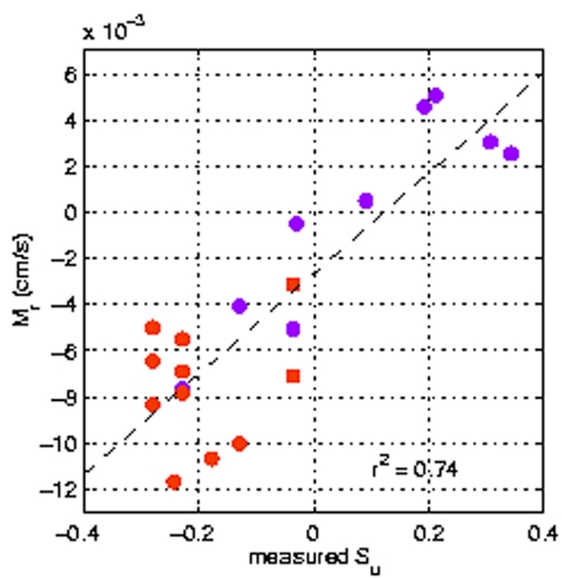

Figure 3: Ripple migration velocity versus wave-orbital velocity skewness from Queensland Beach, NS (Crawford and Hay, 1999).

The question of skewness and its effect on bedform migration velocity is being investigated by Doctoral student Anna Crawford, for O(10cm)-wavelength 2-dimensional ripples at wave energies just below the flat bed transition. A result from her work is presented in Figure 3, which like Figure 2 shows a relationship between nearbed wave orbital velocity skewness and the migration velocity of these ripples. The interesting thing about this Figure is that the observed migration direction was at times offshore, and not only onshore (as in Figure 2 for example), and that the offshore migration occurred at times of negative skewness. There was no significant mean current, either on- or off-shore, during the times when the data in Figure 3 were collected. Thus, negative skewness and offshore sediment transport (if transport can be inferred from the migration of these ripples) arose from the wave motions themselves. Bispectral analysis indicates that the skewness variations in Figure 3 are the result of nonlinear interactions among the components of the wave spectrum. Finally, we have been able to show that the observed skewness values are consistent with second-order nonlinear wave theory.

IMPACT

In the SANDYDUCK'97 experiment, we demonstrated that it is possible to make long-term observations of nearshore fluid-sediment interactions with sophisticated measurement systems on a continuous basis at a number of cross-shore locations. The data set is of high quality and, because of the combination of coherent Doppler profilers, 3-dimensional seabed imaging systems, and the 3-month's duration, it is also unusually comprehensive. In addition, the successful performance of the acoustic remote sensing array throughout SANDYDUCK for a wide range of surf zone conditions opens up a variety of new possibilities for these kinds of instruments in future nearshore dynamics experiments.

During the next several years, we anticipate that comparisons of the SANDYDUCK data with model predictions will yield significant insights into mobile bed dynamics in the nearshore zone, and improved parameterizations for use in nearshore sediment- and hydro-dynamic models. The results presented here underscore the importance of linkages between the small-scale sediment dynamic response and nonlinearities in the fluid motions.

TRANSITIONS

Numbers of groups world-wide are making use of our advances in the use of acoustics for the sediment transport studies, in particular the introduction of rotary imaging sonars for bedform measurements (see Hay and Wilson, 1994).

RELATED PROJECTS

A significant benefit to this project was provided by a grant from the Natural Sciences and Engineering Research Council (NSERC) of Canada to Dr. Alex Hay (Principal Investigator), and Co-Investigators: Dr. Tony Bowen (Dalhousie University), Dr. J. C. Doering (University of Manitoba) and Dr. Len Zedel (Memorial University of Newfoundland), which covered most of our field costs during the SANDYDUCK'97 experiment.

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